LEGACY

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FROM THE PRESIDENT:

Greetings from the American Amaranth Institute. For those of you who were not able to attend the annual meeting of the American Amaranth Institute in Ft. Collins, Colorado, I regret to inform you that you missed a very informative program containing topics ranging from economics to cleaning techniques.

Dr. Gordon Rose, Professor Emeritus, University of Minnesota, spoke on rural economics. Dr. Rose stated that even though we are six years into an economic recovery, we still have extremely slow rural economic recovery and that the poverty rate in rural areas is increasing. Dr. Rose also explained how the source of income has changed for rural America. A ray of hope could be seen in the future for rural America as Dr. Rose examined several alternative strategies for rural economic development.

Next on the program was Dr. Duane Johnson, Department of Agronomy at Colorado State University. Dr. Johnson reviewed how the Colorado Alternative Crops Program was designed and established in 1982. He gave data from the variety and production trials at the different experimental stations in Colorado. Dr. Johnson also discussed nutritional allowances, water, and climatic conditions at the stations.

Steve Holmes from Steve's Feed and Seed Co. in Grant, Nebraska, explained how his company was set up to handle and clean amaranth. Also touched on by Mr. Holmes was possible by-product management and uses of these products.

Leon Weber, Rodale Research Coordinator, Kutztown, Pennsylvania, expertly moderated the Grower Panel made up of experienced amaranth growers. Such topics as fertility, row spacing, seeding rates, planting equipment, planting tips, combine settings, and individual goals were covered.

The next program speaker was an international member of the AAI, Davidson K. Mwangi, of Nanyuki, Kenya. Mr. Mwangi opened our eyes to the extensive work being done by his company in amaranth production, extension work with farmers, and the education needed to bridge the cultural eating habits of the people as they include amaranth into their diet.

Dr. Dan Putman and Jim Stordahl, Department of Agronomy, University of Minnesota, reported on trials at the various Minnesota research stations. Not only were the fertility trials and yield data discussed, but a new and exciting area of research for the United States dealing with amaranth as a forage crop was presented.

There were four major highlights of the Annual Business Meeting. First of all, the Board of Directors was directed to establish an inquirer's list and listing of resources that could be obtained for a fee to help distribute information and to help raise capital to operate AAI.

Larry Walters was asked to continue his work with the USDA on setting standards for clean amaranth.

Mike Irwin was again appointed to head up the Organic Producers Branch of the AAI, and to serve as liaison officer to the food industry for organic standards.

Last of all, I would like to note that new Board members and officers were elected to serve on the Board of Directors of the American Amaranth Institute.

---Wayne Applegate

IN THIS ISSUE

INTERVIEW WITH DR. ROBIN SAUNDERS

Dr. Robin M. Saunders is the Research Leader, Food Quality Research, Western Regional Research Center-ARS-USDA, Albany, California. He directs a broad research and development program on cereal grains, fruits and vegetables, and minor oilseeds and legumes.

Dr. Saunders first became involved with amaranth through USDA efforts on the development of alternative and stress-tolerant crops. His team's research has focused on the nutritional quality of the grain, on milling microstructure, and on processing characteristics.

When asked what amaranth's strongest points were, Dr. Saunders replied, "[they were] the potential for production in semi-arid environments and the potential through breeding/selection for a very high yield per acre."

Dr. Saunders believes that a high grain price with no dependable supply and lack of advantageous competitive functionality in food systems are amaranth's weakest points. He adds, "a real need of the industry is to get a constant supply of the grain at a price competitive with other grains in order to achieve a reliable market niche." For example, in other publications, he has drawn attention to the price of wheat, which in 1988 was 6 cents per pound, while amaranth was being sold for roughly 50 to 89 cents per pound. He believes that the price of amaranth must eventually fall to about 10-15 cents per pound if it is to become a commodity.

In addition to viewing amaranth as a grain, he suggests that the stover, i.e., the residue left after the grain harvest, might be valuable to the animal feed industry or for industrial processing. Of course, this may generate additional income for the producer and thus lower the price of the grain.

Dr. Saunders believes that the processing technology of amaranth needs further development, especially in the areas of milling, extrusion, flaking, and rolling. Special qualities of the grain also should be explored, particularly the applications for and isolation of the micro-crystalline starch granules. Further, dry-milling should be examined because of its ability to yield a 25% germ fraction with 42% protein, which is superior to the dry milled fraction from other cereal grains. As with marketing of any new product, a competitive superiority for amaranth would enhance acceptance.

INTERVIEW WITH MIKE IRWIN

Mr. Mike Irwin of Lodi, Wisconsin, currently serves as secretary of the American Amaranth Institute and is one of seven growers and researchers who founded the organization. Mike is a college teacher, a consultant in alternative crop production, and a specialized writer for a popular farm magazine. He holds a Master's Degree and is currently a contributing editor with WISCONSIN AGRICULTURIST Magazine and a member of the Wisconsin Department of Agriculture Organic Food Standards Advisory Committee.

In early 1989, Mike was awarded a two-year Sustainable Agriculture grant by the State of Wisconsin to demonstrate and compare corn and amaranth profits and energy costs.

Mike has been growing amaranth experimentally and/or commercially for 10 years. He got started by reading an article in RODALE'S ORGANIC GARDENING inviting subscribers to try test plots. Since 1980 he has been a Rodale cooperating grower in organic production and breeding experiments. He grows amaranth with a rotation of row crops, small grains and legumes. His rotation has two simple foundations: legumes fix nitrogen, hold and enrich soil, and feed animals and control weeds. Amaranth and other specialties are grown for their market premiums with cover cropping techniques and intensive cultivation. He says, "I do this for myself and so I can teach others to direct or contract markets and be their own masters."

The amaranth industry needs comprehensive education and outreach work with interested new growers and also research and development in projects in non- chemical weed control options with amaranth. Breeding work is also needed. Amaranth's greatest strengths include its wonderful nutritional qualities and drought-hardiness. Amaranth's weakness is a weakness only in mechanized agriculture.

Mike compares amaranth to a teenager,"half-wild and half- civilized, fighting the combine, spreading itself on the wind, coming out of cool spring ground slow and lazy-behaving like the sub-tropical plant it really is."

"Buy amaranth as a curiosity," and "buy it to be different! Buy it to blend with the bread and pancakes and buy it because almost all of it is grown without chemicals. The most important reason to buy it is because when put with other small grains it makes near-perfect plant protein," says Mike.

WATCH FOR DETAILS ON THE AMERICAN AMARANTH INSTITUTE'S ANNUAL MEETING.

NOVEMBER 10-11 AT KANSAS CITY.

PROTEINS OF GRAIN AMARANTHS

James Lehmann
Institute for the Development
of Amaranth Products, Inc.

Proteins are key structural and regulatory materials in humans. Protein needs of humans vary depending on age, sex, pregnancy, general health, and occupation. Amino acids are the building blocks of proteins and there are over twenty different types of them. Although all of he amino acids are commercially available from chemical suppliers, most people rely upon natural sources to provide them in their diet. Meats, legumes, and cereals are reliable sources of most amino acids that the human body cannot synthesize. In addition, cereals provide about 50% of calories for mankind.

One of the main attributes of amaranth grain is its protein content. Various general amaranth reviews are available which give tables and descriptions of amino acid spectrums and protein qualities (Teutonico and Knorr, 1986; Saunders and Becker, 1984; Singhal and Kulkarni, 1988). In this article, the focus will be on recent or key protein studies.

In 1973, an Australian scientist named John Downton reported that the grain from the pseudocereal amaranth species, Amaranthus edulis Spegazzini (a mutant form of the South American grain amaranth, A. caudatus L.), contained high levels of quality protein (Downton, 1973). What attracted the most attention was large amounts of the amino acid lysine, which is usually low in most cereals. Subsequently, researchers found that some grain amaranths had lysine levels equal to that of casein, the milk protein often used as the nutritional standard (National Research Council, 1984). The significance of this observation is that amaranth protein is rich in the commonly deficient amino acids of most cereal grains, so mixing amaranth with maize, wheat, or rice results in a protein mixture that has the desired amounts of all essential amino acids (National Research Council, 1984). A recent example of research on this topic is the work of Pedersen et al. (1987b). They calculated amino acid scores using the FAO (1973) reference scoring pattern and found that "maize, wheat, sorghum and amaranth [scored] 54, 51, 37, and 74, respectively." A 50/50 cereal/amaranth blend (on a dry weight basis) improved the FAO (1973) reference scoring pattern for maize, wheat, and sorghum by 25, 23, and 31 points, respectively. After conducting rat weight gain trials to test the biological value of these blends, they concluded that amaranth effectively complemented other cereals in varying degrees and that amaranth's amino acids were biologically available. Another recent example of the complemental concept was the proposal of Sanchez-Marroquin et al. (1986) to industrially mill, fractionate, and extrude amaranth to produce cereal/amaranth infant formulas. They tested various infant nutrition formulas (50:50, 60:40) of A. cruentus L. var. RRC 1011 with wheat and oats, and included different protein and starch milled fractions of amaranth. The protein efficiency ratio (PER), Net Protein Retention (NPR), and digestibility relative to casein, of the 40:60 oat/amaranth blend was found to equal commercial soybean/oats infant formulas.

Loss of lysine by heat processing may be an important issue in the commercial processing of amaranths. For example, Betschart et al. (1981) popped A. cruentus seeds at 220° C. for 15 seconds and noted a 15% reduction in total lysine and no change in the PER, whereas Tovar and Carpenter (1982) noted a 30% drop in "reactive" or biologically available lysine after popping A. hypochondriacus seeds. Because lysine levels in amaranth are relatively high compared to most cereals, it is uncertain at what popping temperature one would experience diminishing returns regarding the biological value of lysine. Bressani et al. (1987c) investigated the two amino acids, lysine and tryptophan, in fourteen amaranth selections representing four species, and found a range of from 0.73-0.84% (or 4.68-6.40 g/16 g N) lysine and from 0.18-0.28% (or 1.10-1.87 g/16 g N) tryptophan. Protein quality values, as measured by testing the protein efficiency ratio (PER) of weanling rats, indicated levels at 81-94% of casein (milk protein). In one of the most fundamental human nutrition studies to date, Morales et al. (1988) tested heat processed amaranth products in the diet of nine children and found that 12.7% (by weight) toasted amaranth flour added to maize meal would provide a "nutritionally superior source of protein and fat."

Misra et al. (1983) tested the amino acid profile of six Indian A. hypochondriacus varieties, and found that the crude protein percentages ranged from 15.3% to 22.1% (AG-16, cv. Kerala). Lysine content varied from 3.9 to 6.1% g/100 g protein whereas the often limiting amino acid leucine varied from 4.7 to 6.9 g/100 g protein. The correlation coefficient between lysine and leucine was -0.162. Pant (1985) compared relative NPR of popped and unpopped amaranth seeds from two Indian markets, and found that the relative NPR of unpopped grains was significantly higher than popped grains, 75% to 63%, respectively. Lysine, which may be destroyed by high popping temperatures, was added to both types of grain but the relative NPR was unaffected. Cheeke and Bronson (1979) obtained poor growth in rats fed raw amaranth seed and corn, although cooking the seed improved the growth response.

Pedersen et al. (1987a) evaluated the protein content and quality in four varieties of A. caudatus. Lysine content ranged from 5.2-6.0 g/16g N. Various raw, popped, flaked, and toasted products were evaluated for the first and second limiting amino acids and for their FAO (1973) reference scoring pattern. In 9 of ten products over all four varieties, leucine was the first limiting amino acid, while the reference scoring patterns ranged from 70 to 80. Black seeds had lower protein digestiblity than pale seeds, which seemed to be offset in this study by original protein content.

Traditionally, at least one method of preparing amaranth was as a gruel for infants. Now, modern researchers have documented the nutritional advantages of its use as an infant weaning food. Osuntogun and Oke (1983) analyzed an unidentified Nigerian, A. hybridus variety, and determined a protein efficiency ratio (PER) of 2.3 compared to the experimental value of 2.5 for casein. Misra et al. (1985) analysed nineteen A. hypochondriacus lines for protein contents and found from 8.9 to 16.5% protein. Pant (1983) reported improved NPRs in weanling rats when amaranth was supplemented with wheat and skim milk. Ten varieties, including nine A. hypochondriacus and one A. cruentus, plus three marketplace samples showed lysine in the range from 4.70 to 5.82 g/16g N. Relative to the casein control with a relative NPR of 100, amaranth alone rated 74 while wheat and amaranth in a 6:3 protein mix rated 68. Wheat, amaranth, and skim milk powder in a 5:3:1 ratio rated 75.

Extrusion has often been used to improve the nutrition quality of products (Harper and Jensen, 1985). Mendoza and Bressani (1987) extruded amaranth flour of two amaranth lines (A. caudatus, CAC-38, and GUA-17 (A. cruentus). Both lines exhibited higher NPR at 154° C. than at 146° C. Extrusion improved the NPR in both samples without decreasing the available lysine content. Koeppe et al. (1987) extruded defatted maize gluten meal and A. hypochondriacus seed in an 80:20 ratio, and found that in vitro digestibility varied from 82.1% in the unextruded blend to 85.4% in the extruded blend. However, the biological quality of the new product was not assessed.

Bressani et al. (1987a) tested four amaranth selections for effects of fertilization on protein levels and quality, and determined that fertilization affected protein level but not protein quality. Two selections, A. caudatus (Cusco, Peru CAC-2002) and A. cruentus (US Rodale 81S-1024), displayed 2.2% and 0.4% protein increases, respectively, when 90 kg/ha (12-24-12) NPK was applied as opposed to a control of 0 kg/ha. On the other hand, an A. cruentus selection (GUA-17) showed a decrease in protein level when heavily fertilized while A. hypochondriacus (US Rodale 82S-1034) was not affected.

Fractionation of A. hypochondriacus seed protein into simple proteins has revealed these consituents: albumin (4.4% by weight of the seed), globulin (1.0%), glutelin (0.56%), and prolamin (0.76%) (Abdi and Sahib, 1976). They determined that roughly half of the seed's protein was present in the albumin fraction, with the globulin, glutelin, and prolamin contributing progressively decreasing amounts. Jaiswal et al. (1984) also extracted protein fractions from A. hybridus and observed 8.6% albumin, 4.5% globulin, and 6.1% glutein. Konishi et al. (1985) purified an A. hypochondriacus globulin from a globulin/albumin fraction. This fraction resembled similiar fractions taken from buckwheat (Fagopyrum esculentum Moench.). Four subunits of the globulin protein were detected. Wiesner (1985), while studying efficiency of various milling techniques, also found high levels of albumin and globulin in protein isolates of A. cruentus and A. hypchondriacus. The properties of the protein isolates included, "limited water absorption, poor emulsifying and foaming properties, nitrogen usually soluble at elevated pH's, and firm gels at lower concentrations than 'high gelling commercial soy protein isolates' (Wiesner, 1985)."

The relationship between antinutritional factors and amaranth protein quality has never been firmly established. It is tempting to speculate that indigenous heating methods may have inactivated thermolabile, antinutritional factors in grain amaranths. For example, Early and Early (1988) have documented native popping and roasting techniques in both the Andean and Middle American regions. Again, the degree of thermal processing may have some influence on protein quality. This topic will be addressed in a future article.

Pandey and Pal (1985) probed the genetics of grain protein in Indian A. hypochondriacus matings, and found that highly significant differences ($P \leq 0.01$) among crosses and parents per se and significant differences ($P \leq 0.05$) between parents and crosses. Specific combining ability for protein was present in both the hybrid and segregating generations, which suggested that effective breeding schemes could be applied to improving amaranth protein. To maintain amaranth's high lysine content compared to most cereals, Bressani et al. (1987c) proposed that future selection and breeding programs should maintain levels of at least "400 mg g^{-1} N on the basis of an 85% true protein digestibility."

AREAS FOR FURTHER STUDY

1. Effects of elevated popping or roasting temperatures on lysine and other amino acid levels.
2. Evaluation of amaranth protein and starch fractions in various species and varieties.
3. Identification of plant proteins in amaranth varieties by reversed-phase, high performance

liquid chromatography (RP-HPLC).
4. Regional testing of amaranth varieties to investigate protein X environment interactions.
5. Extrusion and heat processing effects on protein quality and thermolabile, antinutritional factors.
6. Characterization of the subunits and properties of amaranth globulins (Konishi et al., 1985) and albumins.
7. Breeding for improved leucine and threonine levels.

COMMENTARY

The relatively high lysine content of grain amaranths is insufficient reason to justify their improvement to the level of modern, staple crops. Recent CIMMYT progress in producing quality protein maize (QPM) suggests that the protein levels of corn can be also modified to produce superior human and animal foods. However, if one considers that various amaranth/cereal blends may accomplish the same goal, more weight is added to the improvement argument. For example, Morales et al. (1988) propose that if toasted amaranth is blended with corn in a 1:8 ratio, it could provide most of the protein and fat needs of young children. This study assumes that the amaranth provides 20% of the protein.

It is noteworthy that sorghum and wheat, two dryland cereals, are also nutritionally fortified by amaranth blends. If drought tolerant grain amaranths can be effectively integrated into dryland farming systems, a livestock feed niche is conceivable. Ultimately, though, the economics of amaranth production will be decided on the basis of total protein and quality protein yield. The back-up or additional uses of amaranths as grain, forage, or vegetables may provide the flexibility needed to integrate the crop into existing farming systems.

One summer when I was touring northern Wisconsin, I saw empty and discarded barrels of imported, Asian lysine lying beside the antique shop we were visiting. Such lysine is added to domestic cereals and it may or may not be economical to do so. Trade in nutritional supplements and agricultural commodities does have a bearing on crop development. Such trade is wrapped up in politics, polemics, protectionism, and currencies as witnessed by the ongoing General Agreement on Trade and Tariffs (GATT) talks. Domestic self sufficiency in protein production and full utilization of renewable resources in any country, I believe, will help create a more sustainable and well-balanced agriculture.

Amaranths are not leguminous crops and hence do not build up the nitrogen of the soil as they extract nitrogen to build proteins. Their inclusion in monoculture cropping systems must be tempered by this realization. However, their use as green manures has not been thoroughly tested. Appropriate amaranth crop rotations, double crops, intercrops, and relay crops which maintain soil tilth and fertility should be sought.

AMARANTH PROTEIN LITERATURE with ANNOTATIONS

Abdi, H., and M.K. Sahib. 1976. Distribution of lysine in different legumes an some species of Amaranthus seeds. J. Food Sci. Technol. 13237-239. (Describes the lysine and protein content of six amarnth lines and the protein fractions of an A. hypochondriaus line.)

Afolabi, A.O., O.L. Oke, and I.B. Umoh. 1981. Preliminary studies on the nutritive value of some cereal-like grains. Nutrition Reports International. 24(2): 389-394. (Investigated the protein quality and PER of an A. caudatus line.)

Betschart, A.A., Irving, D.W., Shepherd, A.D., and Saunders, R.M. 1981. Amaranthus cruentus: milling characteristics, distribution of nutrients within seed components and the effects of temperature on nutritional quality. J. Food Sci. 46:1181-1187. (Effects of milling with a modified barley pearler were studied by histological, nutritional, and chemical methods.)

Bressani, R., L.G. Elías, J.M. Gonzàlez, and R. Gómez-Brenes. 1987a. The chemical composition and protein quality of amaranth grain germplasm in Guatemala. Archivos Latinoamericanos de Nutricion. 37:365-377. (Thirty-five amaranth accessions, including 27 accessions from Guatemala, were tested for protein and were found to contain a range from 12.8% to 17.4%.)

Bressani, R., J.M. Gonzalez, L.G. Elias, and M. Melgar. 1987b. Effect of fertilizer application on the yield, protein and fat content, and protein quality of raw and cooked grain of three amaranth species. Plant Foods for Human Nutrition. 37:59-67. (Investigated the effect of fertilization on protein quality and yield in A. cruentus, A. hypochondriacus, and A. caudatus.)

Bressani, R., J.M. Gonzales, J. Zuniga, M. Breuner, and L.G. Elias. 1987c. Yield, selected chemical composition and nutritive value of 14 selections of amaranth grain representing four species. J. Sci. Food Agric. 38: 347-356. (Investigated the protein efficiency ratio (PER) in A. hybridus, A. hypochondriacus, A. cruentus, and A. caudatus. Mineral composition and key amino acids were also monitored.)

Calderon de la Barca, A.M., J.L. Ochoa, and M.E. Valencia. 1985. Effect of the extraction of a hemagglutinin on the nutritive value of Amaranthus leucocarpus seeds. J. of Food Sci. 50:1700-1702. (A study which suggests that saline extraction of an A. l.. .... hypochondriacus (syn. A. leucocarpus) lectin improves the PER and NPR of whole meal.)

Carlsson, R. 1979. Quantity and quality of Amaranthus grain from plants in temperate, cold and hot, and subtropical climates-a review. In Proc. First Amaranth Conference, Rodale Press, Emmaus, PA. (An early seed and protein yield study of 25 amaranth lines which represented nine species.)

Cheeke, P.R., and J. Bronson. 1979. Feeding trials with Amaranthus grain, forage and leaf protein concentrates. In Proc. First Amaranth Conference, Rodale Press, Emmaus, PA.

Conner, J.K., R.J.W. Gartner, B.M. Runge, and R.N. Amos.

1980. Amaranthus edulis: an ancient food source re-examined. Aust. J. Exp. Agric. Anim. Husb. 20: 156-161. (The study examined the protein content, amino acid spectrum, and metabolizable energy in raw and autoclaved A. caudatus var. edulis.

Correa, A.D., L. Jokl, and R. Carlsson. 1986. Chemical constituents, in vitro protein digestibility, and presence of antinutritional substances in amaranth grains. Archivos Latinoamericanos de Nutricion. 36(2): 319-326. (Gives data on protein levels and protein digestibility for Amaranthus anclancalius, A. tricolor (A. gangeticus), and A. hypochondriacus grown in Brazil, Puerto Rico, and California).

Downton, W.J.S. 1973. Amaranthus edulis: a high lysine grain amaranth. World Crops 25:20. (An early report of the protein contents of A. caudatus var. edulis.)

Early, D.K., and J.C. Early. 1987. Transference of autoctonous technology for the preparation of kiwicha (Amaranthus). Part I. Amaranth Newsletter No. 4, Institute for Nutrition of Central American and Panama, P.O. Box 1188, Guatemala City, Guatemala. (Describes indigenous techniques for popping and roasting amaranth in Mexico and Peru).

Ensminger, A.H., M.E. Ensminger, J.E. Konlande, and J.R.K. Robson. 1983. Food and Nutrition Encyclopedia. Pegus Press, Clovis, CA. pp. 1860-1888. (A general review of proteins, their functions and evaluation.)

Feine, L.B., R.R. Harwood, C.S. Kauffman, and J.P. Senft. 1979. Amaranth: gentle giant of the past and future. In Ritchie, G.A. (ed.) New Agricultural Crops. AAAS Selected Symposium #38. Westview Press, Inc., Boulder, CO. (An early, general summary of grain and vegetable amaranths.)

Food and Agriculture Organization. 1973. Energy and protein requirements. Nutr. Rep. Ser. No. 52. Rome: FAO.

Garcia, L.A., M.A. Alfaro, and R. Bressani. 1987. Digestibility and protein quality of raw and heat-processed defatted and nondefatted flours prepared with three amaranth species. J. Agric. Food Chem. 35(4):604-607. (A study conducted to test protein quality after hexane extraction).

Harper, J.M., and R. Jansen. 1985. Production of nutritious precooked foods in developing countries by low-cost extrusion technology. Food Rev. Int. 1:27.

Imeri, A., J.M. Gonzalez, R. Flores, L.G. Elías, and R. Bressani. 1987. Genetic variability and correlations between yield, grain size, chemical composition, and protein quality of 25 varieties of amaranth (Amaranthus caudatus). Archivos Latinoamericanos de Nutricion. 37(1):132-146. (The average protein content of the 25 varieties was 12.7% and the amino acid, leucine, was deficient in all varieties.)

Jaiswal, S., B.K. Mehta, and S. Jain. 1984. Protein bound amino acids of medicinally important plant seeds. Plantes Medicinales et Phytoterapie 18(4):248-254. (Reviews the amino acid spectrum of the albumin, globulin, and glutelin fractions of Amaranthus hybridus.)

Koeppe, S.J., P.L. Harris, M.A. Hanna, J.H. Rupnow, C.E. Walker and S.L. Cuppett. 1987. Physical properties and some nutritional characteristics of an extrusion product with defatted amaranth seeds and defatted maize gluten meal (80:20 ratio). Cereal Chem. 64(5):332-336. (A study to test the effectiveness of A. hypochondriacus in improving maize gluten meal.)

Konishi, Y., Y. Fumita, K. Ikeda, K. Okuno and H. Fuwa. 1985. Isolation and characterization of globulin from seeds of Amaranthus hypochondriacus. Agricultural and Biological Chemistry. 49(5): 1453-1459. (A study of the subunits of an amaranth protein fraction, globulin.)

Laovoravit, N., F.H. Kratzer, and R. Becker. 1986. The nutritional value of amaranth for feeding chickens. Poultry Sci. 65(7): 1365-1370. (A nutritional study of A. cruentus which monitored the availability of lysine. Chick growth with raw and autoclaved amaranth were compared.)

Mendoza, C., and R. Bressani. 1987. Nutritional and functional characteristics of extrusion-cooked amaranth flour. Cereal Chemistry. 64(4): 218-222. (Protein quality of extruded amaranth of two species was monitored. A highly nutritious, instant drink was prepared.)

Misra, P.S., R.M. Pandey and M. Pal. 1983. Amino acids composition in Amaranthus. Fitoterapia. 54(3): 135-139. (Amino acid profiles and correlations between amino acids were monitored in six varieties of A. hypochondriacus.)

Misra, P.S., D. Prakash, R.M. Pandey, and M. Pal. 1985. Protein and amino acid composition of grain amaranth seeds. Fitoterapia. 5: 318-320. (Surveys the amino acid spectrum of 19 Indian, A. hypochondriacus lines.)

Morales, E., J. Lembcke, and G.G. Graham. 1988. Nutritional value for young children of grain amaranth and maize-amaranth mixtures: effect of processing. J. Nutr. 118:78-85. (The nutritional quality of A. caudatus, as toasted flour, flakes, and popped seeds, was assessed in children's diets where amaranth was the sole source of protein and fat.)

National Research Council. 1984. Amaranth: modern prospects for an ancient crop. National Academy Press, Washington, D.C.

Osuntogun, A.B., and O.L. Oke. 1983. A note on the nutritive value of amaranth seeds. Food Chemistry. 12(4):287-289. (Analysis of protein and protein performance in an African vegetable type, A. hybridus.)

Pandey, R.M. and M. Pal. 1985. Genetics of grain protein in Amaranthus. Crop Improv. (India) 12(1): 55-58. (Protein inheritance is studied in a mating design of Indian, A. hypochondriacus.)

Pant, K.C. 1983. Studies on the nutritional quality of grain amaranths. Nutrition Reports International. 28(6): 1445-1456. (Formulation of wheat/amaranth blends and weaning foods is proposed.)

Pant, K.C. 1985. Effect of heat processing (popping) on protein nutritional quality of grain amaranth. Nutrition Reports International. 32(5):1089-1098. (Nutritional losses in commercially- and home-popped amaranths, probably A. hypochondriacus, are compared.)

Paredes-López, R. Mora-Escobedo, and C. Ordorica-Falomir. 1988. Isolation of amaranth proteins. Lebensm.-Wiss. u.-Technol. 21:59-61. (A. hypochondriacus, 78S-125 Nepal type, was analyzed for glutelins, proteins soluble in dilute acids or bases, and albumins/globulins, which were present at levels of about 30% and 46%, respectively.)

Pedersen, B., L.S. Kalinowski, and B.O. Eggum. 1987a. The nutritive value of amaranth grain (Amaranthus caudatus): 1. Protein and minerals of raw and processed grain. Plant Foods for Human Nutrition. 36: 309-324. (Effects of popping, toasting, and flaking were studied by proximate analysis and with test animals.)

Pedersen, B., L. Hallgren, I. Hansen and B.O. Eggum. 1987b. The nutritive value of amaranth grain (Amaranthus caudatus): 2. As a supplement to cereals. Plant Foods for Human Nutrition. 36:325-334. (Wheat, maize, and sorghum blends with amaranth were studied in test animals.)

Sanchez-Marroquin, A., M.V. Domingo, S. Maya, and C. Saldana. 1985. Amaranth flour blends and fractions for baking applications. Journal of Food Science. 50: 798-794. (Various wheat/amaranth blends were tested and enriched cookies and French bread were recommended as fortified products.)

Saunders, S.R. 1987. Milling amaranth with tangential abrasive dehulling device. M.S. thesis, Kansas State Univ., Manhattan, KS. (Protein curves and proximate analysis were done after milling trials.)

Saunders, R.M., and R. Becker. 1984. Amaranthus: a potential food and feed resource. Advances in Cereal Science and Technology 6:357-396. (A general summary of amaranth literature and topics.)

Singhal, R.S., and P.R. Kulkarni. 1988a. Review: amaranths-an underutilised resource. International J. Food Sci. Techn. 23:125-139. (A recent review of amaranth which contains over 130 references, including many references to Indian publications.)

Singhal, R.S., and P.R. Kulkarni. 1988b. Composition of seeds of some Amaranthus species. J. Sci. Food Agric. 42:325-331. (Five Indian amaranths, including A. paniculatus [A. cruentus], were analyzed for protein, starch size, oxalates, and phytates. A. tenuifolius seed was 23% protein.)

Teutonico, R.A. and D. Knorr. 1985. Amaranth: composition, properties, and applications of a rediscovered food crop. Food Technology. 39: 49-61. (Another general summary of amaranth from a food science perspective.)

Tillman, P.B. 1987. An evaluation of grain amaranth (Amaranthus cruentus) as a feed ingredient for poultry. Dissertation Abstracts International. 48(5):1199B. (Apparent amino acid availabilities were tested in chickens using extruded A. cruentus.)

Tillman, P.B., and P.W. Waldroup. 1987. Processing amaranth for use in broiler diets. Poultry Science 10:1960-1964. (A. cruentus, if autoclaved or extruded, can be included in poultry diets at levels up to 40%.)

Tovar, L.R., and K.J. Carpenter. 1982. The effects of alkali-cooking of corn and supplementation with amaranth seed on its deficiencies in lysine and tryptophan. Archivos Latinoamericanos de Nutricion. 32(4): 961-972. (Popped A. hypochondriacus seeds were added to boiled corn and tortillas to raise lysine and tryptophan levels.)

Uzo, J.O., and A.U. Okori. 1983. Amaranthus hybridus: a potential grain crop for West Africa. Nutrition Reports International 27(3):519-524. (A crude protein and amino acid spectrum of five cultivars of A. hybridus (African vegetable type.)

Van Etten, C.H., R. W. Miller, and I.A. Wolf, and Q. Jones. 1963. Amino acid composition of seeds from 200 Angiospermous plant species. Agric. Food Chem. 11(5):399-410. (Amino acid analysis of A. retroflexus.)

Wiesner, T.A. 1986. Milling evaluation and protein isolates of amaranth grain. Dissertation Abstracts International. 46(10):DA 8528060. (Milling A. cruentus and A. hypochondriacus seed to isolate albumins and globulins.)

GLOSSARY

Biological Value (BV). A measure of the digestible protein actually used by the body. It is calculated by the following equation:

$$BV\ (\%) = \frac{100 \times \text{Nitrogen (N) intake} - [\text{feces N} - \text{metabolic N/urine N} - \text{endogenous N}])}{\text{N intake} - (\text{feces N} - \text{metabolic N})}$$

Lysine. An essential amino acid which cannot be manufactured in the human body. Chemically, it is alpha, epsilon-diaminocaproic acid, $C_6H_{14}N_2O_2$. Lysine is used by the body to regulate calcium and in the formation of collagen (a protein involved in forming a matrix for bone and cartilage).

Net protein ratio (NPR). A protein quality method which improves on the PER by including a control group of test animals who receive no dietary protein. Enminger et al. (1983) describe NPR as "the weight gain of a group of animals (rats) fed the test diet plus the weight loss of a similar group fed a protein-free diet, and the total divided by the weight of the protein consumed by the animals on the test diet."

Net Protein Utilization (NPU). First, digestibility is calculated by monitoring the amount of protein ingested and egested, which is then expressed as a percentage of the amount ingested. The biological value (BV) multipled by the digestibility yields NPU.

Protein efficiency ratio (PER). A simple measure of protein quality where the weight gain of a test animal is divided by its protein consumption over a given test period, usually one to two weeks.

Figure 1. Diagram of longitudinal and cross sections of amaranth seed. In A. cruentus, sixty-five per cent of the protein is located in the embryo and seed coat while the remainder is in the starchy perisperm (Betschart et al., 1981).

Diagram courtesy of D.W. Irving, USDA Western Regional Research Center.